The Strength of Square Plates with Webs.

Guy A. Luburg, 1903

36

The Strength of Square Plates with Webs.

The design of square flat plates subjected to uniform pressure and held down by bolts has been worked out and a full discussion of it can be found in the Thesis of Mr. Moody. In his Thesis, he has worked out a formula which although it is irrational, gives a good design for square cast-iron plates. The design of square plates with webs, however, has not received attention from anyone to my knowledge. It is a very intricate proposition and a rational formula would be very hard to work out. For that matter, to my knowledge, no rational formula has been worked

out for plates without webs.

The object of this thesis is to find out a formula for plates with webs, to find out the best proportions for the webs and to find out the relation of the breaking pressures to dimensions of the plate and webs. The webs are of uniform width but of such height that they are approximately uniform strength. The webs run parallel to the sides of the plate.

In Mr. Moody's Thesis, he has shown that the webs on plates should be on the compression side and not on the tension side. If the webs are placed on the tension side, the plate is found to be weaker than if the plate had no webs. This is most probably due to the fact that cast-iron has a much greater compressive than tensile

strength. The distance from the neutral surface to the uppermost fibre of the rib is so great that this fibre breaks under a small load, since the stress is proportional to the distance from the neutral surface. After this fibre breaks, those below it give way until the rib is broken as far as the plate. The plate is now in the condition of having stiffening ribs running from the centre to the sides but not supported at the centre. The radius of curvature of the bent plate is very small at the centre, and the plate breaks under a smaller load than it would have carried if it had been unribbed. If however, the ribs are put on the compression side, the proportionately high compressive strength to the tensile strength will cause the plate to break on the tension side which will be on the unribbed side of the plate.

The ribs therefore if placed on the compression side of the plate, that is, the side upon which the pressure is exerted, will tend to strengthen the plate. This fact should be borne in mind because cylinder-heads, valve chest covers, etc. generally are designed so that the ribs are on the tension side of the plate and are therefore a detriment rather than a help.

The reason for placing the ribs parallel to the sides is that they have the shortest span, considered as a beam.

In this discussion upon webbed plates, the formula offered by Mr. Moody is assumed to be correct for unribbed plates. It is

$$h = .4414\, a \sqrt{\frac{p}{S}}$$

where h is the thickness of the plate in

inches, .4414 is a numerical constant, <u>a</u> is the length of a side of the plate in inches, <u>p</u> is the breaking pressure in pounds per square inch and S is the modulus of rupture of the material.

Discussion.

One way of attacking such a problem as the design of ribbed plates was given by Mr. Moody in his thesis. It is briefly this:-

Figure 1 shows a square plate with a section taken along a diagonal. The reactions along the sides may be considered to be arranged symmetrically in magnitude about the centres of the sides. The resultant of the reactions along one side is seen to pass through the centre of the side. Each side supports one quarter of the load so that the resultant of the reactions for the section taken equals $\frac{1}{2} a^2 p$ and is applied at a distance $\frac{1}{2} a \sqrt{\frac{1}{2}}$ from the diagonal section.

The only force acting on this side of the diagonal is the resultant pressure on half of the plate which is also $\frac{1}{2} a^2 p$ in

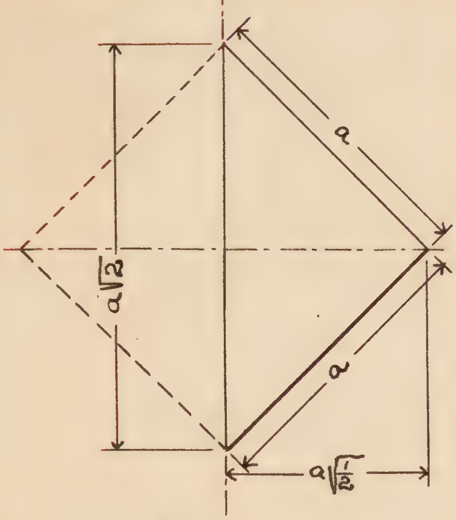


Fig. 1.

magnitude but is applied at the centre of gravity of the triangular area or at a distance $\frac{1}{3}a\sqrt{\frac{1}{2}}$ from the diagonal section. The moment about the diagonal section of all the forces on one side is

$$M = \frac{1}{2}a^2 p\,\frac{1}{2}a\sqrt{\frac{1}{2}} - \frac{1}{2}a^2 p\,\frac{1}{3}a\sqrt{\frac{1}{2}} = \frac{1}{12}a^3 p\sqrt{\frac{1}{2}}$$

This bending moment is equal to the resisting moment of the diagonal section. This resisting moment is equal to $K\frac{SI}{C}$ where K is a constant due to the stress being not uniform across

the plate and the coefficient of lateral contraction of the material. The formula becomes $\frac{1}{12} a^3 p \sqrt{\frac{1}{2}} = K \frac{SI}{c}$

By making experimental tests, the value of K can be found, all the other parts of the formula being known. From the experiments made however on cast iron ribbed plates, this formula would not hold. This was due to the plate breaking on the tension

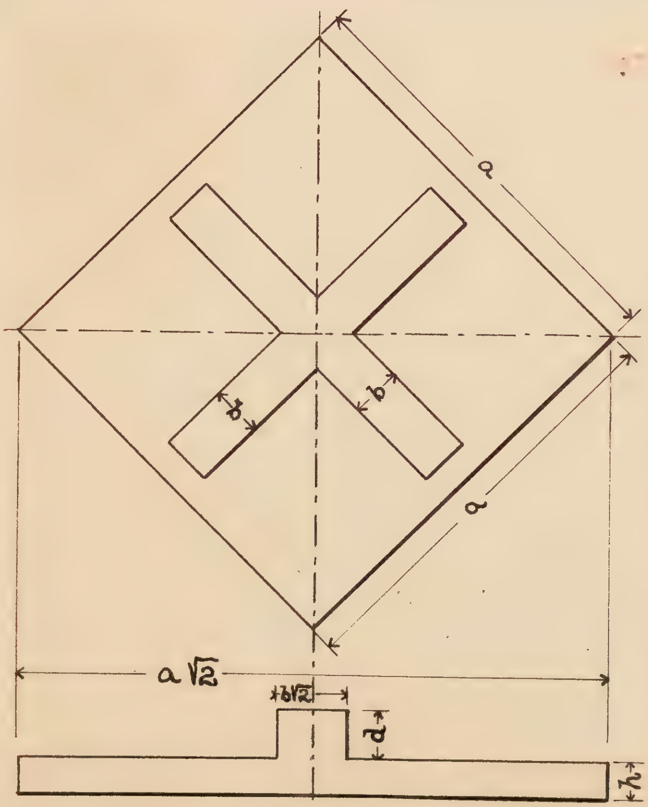


FIG. 2

side, that is, the side without the ribs. Therefore the distance from the neutral surface to the outermost fibre called c is taken to the surface of the plate without webs. Very slight (See Fig 2) differences in the thickness of plates has a very great effect upon this value of c compared to the effect due to variations in the height of the web d. In the plates tested, this effect was very noticable and made this method of attacking the problem of no use.

Another method was then tried. Curves were plotted with breaking pressures as abscissae and dimensions of the different plates as ordinates. These plates had all the same thickness but the heights of their webs were different, the widths of the webs remaining constant. The variations of breaking pressures were therefore due to the different sizes of the webs. A curve with total height of web plus thickness of plate as

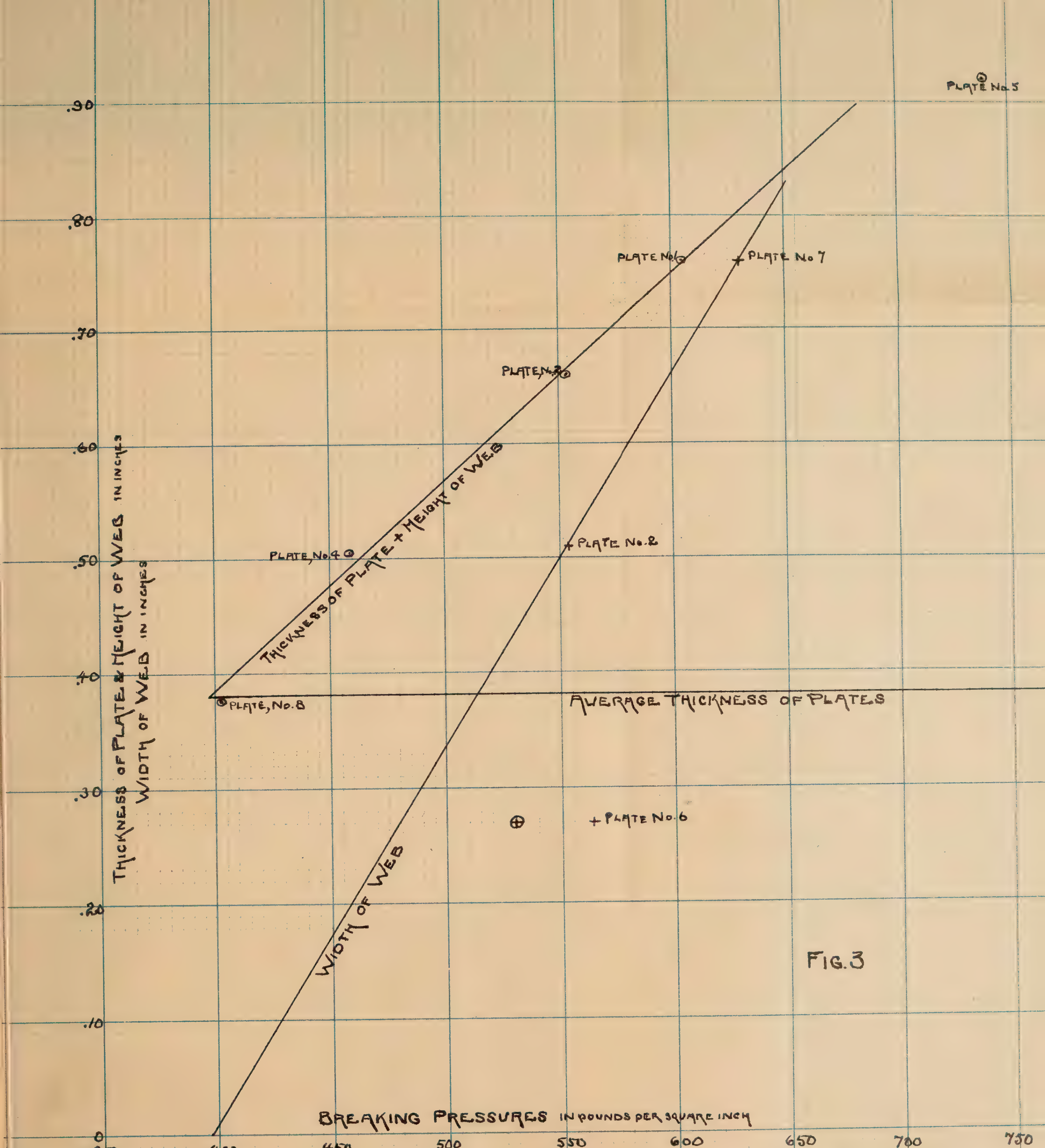


FIG. 3

RELATION OF PLATE & WEB DIMENSIONS
TO
BREAKING PRESSURES

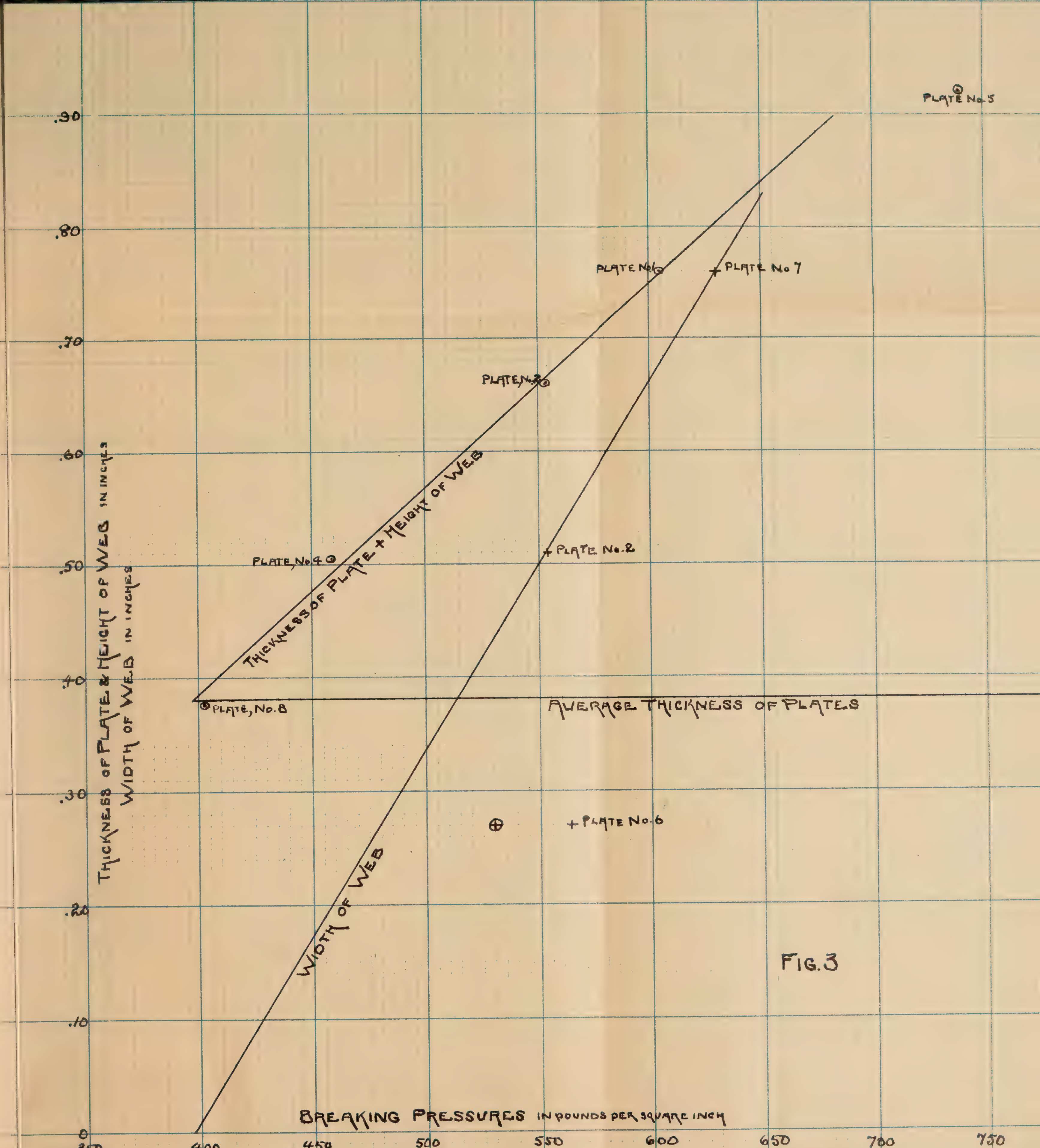


FIG. 3

RELATION OF PLATE & WEB DIMENSIONS
TO
BREAKING PRESSURES

ordinates and breaking pressures as abscissae for the different plates was found to be (See Fig 3) very close to a straight line. This line came very close to going through the point of the plate which had no web. This showed that for plates with constant thickness and webs of constant width, the extra pressure needed to break the plate above that pressure needed to break the plate if it had no webs is proportionate to the height of the web. Let us call this pressure p_3. An assumption must now be made in order to have this relation hold for plates of any thickness. It is this. If the thickness of the plate is increased, the web dimensions remaining constant, the pressure p_3 in its relation to the total breaking pressure will be decreased in the same ratio or

$$p_3 \propto \frac{d}{h}$$

where d is the depth of the web and h is the thickness of the plate. This pressure p_3 is also

inversely proportional to a^2 where a is the length of one side of the plate. This assumption is taken from the formula

$$h = .4414\, a \sqrt{\frac{p}{S}}$$

$$p = \frac{S h^2}{.4414\, a^2}$$

As the pressure p varies inversely as a^2, it is assumed that the extra pressure due to the webs will vary in the same way. Also, the pressure p_3 will vary in the same ratio as S_r (modulus of rupture). From this we get

$$p_3 = K \frac{d}{h} \frac{S}{a^2}$$

The original formula $p = \dfrac{S h^2}{.4414\, a^2}$ now

becomes $p = \dfrac{S h_2}{.4414\, a^2} + K \dfrac{d}{h} \dfrac{S}{a^2}$

K in this formula is an experimental constant and is obtained from the straight line law of the pressure p_3 as related to the height

of the web. This formula is of course of no use on account of the breadth of the web not entering into it. This formula would only be good for plates with webs of widths which are equal to the widths of the webs on the plates which were tested in order to get the constant K.

To change the formula so as to take account of the width of the web to have an effect, a curve was plotted making widths of web as ordinates and breaking pressures as abscissae. This was done for plates which had constant thickness and webs of constant height. This curve came (Fig 3) very nearly a straight line and was assumed to be such. The same assumption was made as for the plates with webs of constant breadth and varying height or making p_4 the increase in pressure due to webs,

$p_4 \propto \frac{b}{h}$ where b is the breadth of the

web in inches, h is the thickness of the plate in inches. The value of p_4 will vary as S_r (modulus of rupture) and inversely as a^2 where a is the length of one side of the plate. We get $p_4 = F \frac{b}{h}\frac{S}{a^2}$ where F is a numerical constant obtained from the curve in Fig. 3. Now putting this value of p_4 in the formula, the fact that the ~~formula~~ so far is for webs of a certain width, which we will call <u>m</u>, the value of b in the equation for p_4 must have m subtracted from it or

$$p_4 = F \frac{b-m}{h} \frac{S}{a^2}$$

b and m must be added algebraically so that if b is less than m, p_4 will come out negative as it should.

Our final value of the breaking pressure will be equal to $p + p_3 + p_4$ or

$$P = \frac{Sh^2}{.4414\,a^2} + K\frac{d}{h}\frac{S}{a^2} + F\frac{b-m}{h}\frac{S}{a^2} \quad \text{or}$$

$$P = \frac{S}{a^2}\left(\frac{h^2}{.4414} + K\frac{d}{h} + F\frac{b-m}{h}\right)$$

It was found by experiment that plates with small webs would break in the centre while plates with heavy webs would break around the edge of the plate at the ends of the webs. It was experimently found

what would be the approximate dimensions of the web and plate so that it would be equally liable to break at the centre or side, that is, that it was of constant strength approximatly at all points in the plate.

Means of Testing

The apparatus consists essentially of two parts; the pump and the case for holding the plates. The pump is very simple in (Fig. 4) construction and consists of a plunger working through a stuffing box and actuated by a lever. A check valve is at the intake and discharge openings of the pump. The water going into the pump is obtained from a bucket from which a hose goes to the pipe leading to the pump. The pipe leaving the pump goes to an apparatus much like a (Fig. 4) Crosby Gauge tester. It consists of a piston working in a stuffing-box and held down by a lever. Between the lever and the piston is a ball bearing joint which allows the piston to be revolved. This is done so that while the piston is being

raised and lowered it can be revolved and thus eliminate friction. This part of the apparatus is used for calibrating the gauge.

The pipe now goes from the gauge (Fig. 4) calibrating device to a stop valve, then to a drain valve and then to the casing for holding the plates. This casing is in two parts. The base consists of an iron casting which is hollow. The pipe leading from the pump goes to this hollow space. The top surface of this base is planed off flat. The cover is bolted on the top of the base and consists of an iron casting with a hole $7\frac{1}{2}''$ square cut in it. Its lower surface is planed off flat and the plate to be tested is finished off flat where it comes in contact with the cover and is bolted to it on its under side by means of sixteen one-half inch bolts. The cover is placed on the base,

the plate going into the cavity in the base. The cover is bolted on the base with sixteen one inch bolts. The pressure gauge is connected on a T and is placed between the gauge calibrating apparatus and the stop cock. This part of the apparatus was fully described in the Thesis of Mr. G. C. Kelley '01 who designed it.

A "deflectometer" is used for measuring (Fig 4) the deflections of the plates under pressure. It consists of a wooden beam resting upon two supports in a line at right angles to its length which rest in two centre punch marks in wrought iron nails which were driven into a wooden framework which was held rigid on the apparatus. These two supports consist of a small wooden cross bar on the deflectometer into the ends of which wood screws were fastened. These wood screws were sharpened into fine points. At a point along

the length of the deflectometer exactly one inch from the line joining the two supports is a centre punch mark placed in a metal plate which is fastened to the deflectometer. The long end of the beam is about 48 inches long measured from the line joining the two supports. A wire is run from the end of the beam and is bent at right angles at a point exactly 50 inches from the line joining the two supports.
The other end of the deflectometer is much shorter and has a small counter poise weight which can be moved along until the centre of gravity of the beam comes between the centre punch mark and the line joining the two supports. The wooden framework which holds up the deflectometer is made so that the centre punch mark on the deflectometer comes directly above the centre of the plate to be tested. The centre punch

mark on the deflectometer rests on the sharpened end of a small cylindrical iron rod. The other end of this rod is sharpened and rests in a centre punch mark placed in the centre of the plate. This rod is made so that its length is adjustable in order to adjust the deflectometer. This was done by making the rod in two parts, both of which were threaded and screwed into an iron sleeve. Now when the plate is bulged up in the centre by the water pressure, the deflectometer rotates and as the lever arm to the wire at the end of the deflectometer is 50 inches and that to the iron rod is only one inch, the deflections of the plate will be multiplied by fifty as read on the wire. A scale divided into fiftieths of an inch is placed at the wire so that for one division rise of the wire on the scale, the plate will deflect .0004 inch. The deflectometer is

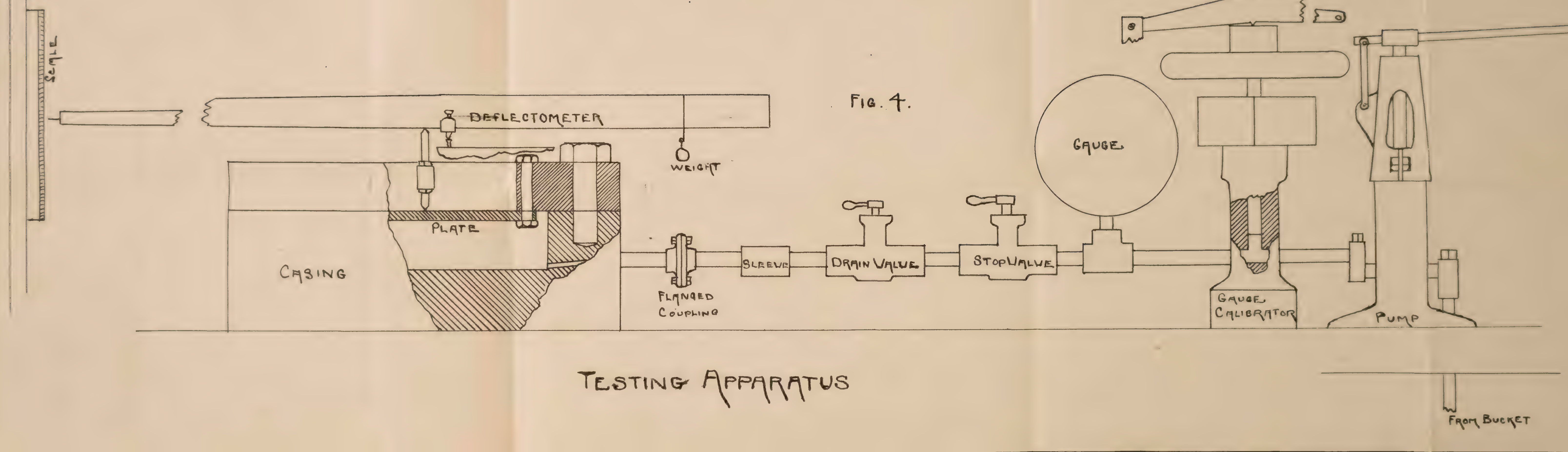


FIG. 4.

TESTING APPARATUS

fully described by Mr. L. F. Moody '01 in his Thesis upon flat plates. Fig. 4 shows the arrangement of the apparatus better than I can describe it in the relations of the different parts to each other. Between the gauge calibrator and the gauge is a branch pipe which goes to apparatus which was used by Messrs. Hood and Redfield in their Thesis work. This pipe is closed off by a stop valve and does not enter into the apparatus used by the tests on the flat plates.

The Tests.

The apparatus, with the exception of the adjustable rod which ran from the deflectometer to the plate, was in working condition. The rod was ordered and the check valves were overhauled. The testing plates and specimens were ordered. The first lot which was ordered consisted of plates $\frac{3}{8}$" thick and with webs $\frac{1}{2}$" wide. These plates had webs $\frac{1}{8}$", $\frac{1}{4}$", $\frac{3}{8}$" and $\frac{1}{2}$" high respectively. These plates were made $1\frac{1}{4}$" wider than neccessary so that bending specimens could be cut directly from the plates. Tension specimens, two in number, and two torsion specimens were ordered. All these specimens and plates were cast from the same heat so the the quality of the iron was the same for all specimens. The tension specimens were made of the same thickness as the plates

so that the effect of the chilled surfaces would be the same on the plates as on the tension specimens. When the plates and specimens arrived, the plates were finished only where they formed the watertight joint with the cover of the plate casing. The bolt holes were then bored, and the plates were ready for the tests. The torsion specimens were tested in the torsion machine just as they were with no finishing. The tension pieces were tested in the same way. The bending specimens after being cut from the plates were tested without having their surfaces finished. The reason for not taking the chilled surfaces off of the specimens was that the chilled surfaces were to effect them just as they effected the strength of the plates.

The gauge was a hydraulic gauge and registered up to 4000 pounds per square inch. It was calibrated by means of the

calibrator which has been described. The relation of the pressure of the water in pounds per square inch to the weight hung on the end of the lever arm was found to be twenty. The gauge was calibrated in the same way as is done in the Crosby Gauge Tester. A known weight was hung on the lever arm and the pump was worked until the calibrator piston arose to the top of its stroke. The piston was revolved by the small hand wheel placed on the top of it and the gauge reading was taken. The true pressure was found by multiplying the lever weight by twenty. This was done for pressures up to fifteen hundred pounds. The machine will not stand pressures above fifteen hundred pounds per square inch. The calibration curve was taken from these readings.

After the first plate had been broken,

some one changed the gauge calibration and it had to be calibrated over again.

The plates were next to be tested. Their dimensions were first measured up. This was done by means of calipers and a scale reading to hundreths of an inch. The thickness of the plates was measured both at the middle and at the sides. The widths and depths of the webs at the centre were measured. The opening in the cover of the casing was measured as this dimension is the a or length of the side of the plate. The cover was then taken off of the base of the casing. This was done by means of a hoist. The plate to be tested was then placed on the cover and the bolts are inserted. The bolt heads and nuts are packed with candle wick soaked with red-lead. Between the plate and the cover is placed a layer of

Duplex paper. This paper forms a very good packing. The bolts were then drawn up with a large wrench. It was found that these bolts were too small and several were broken in tightening them up. The cover was then lowered down over the base. The surface of contact between the cover and the base, inside of the large bolts had a packing layer consisting of two thicknesses of Duplex paper. The nuts were then drawn up with a large wrench. The wooden framework for holding the deflectometer was then fastened on and the deflectometer was put on and adjusted. The scale for reading deflectometer readings was fastened to an upright stand and set at the wire at the end of the deflectometer. The plate was now ready for the test. One person took deflectometer readings while another worked the pump and also kept the pressure

constant while the deflectometer readings were being taken. These readings were taken for every fifty pounds of gauge readings. The pressure at which the plate broke was recorded and the place at which it broke first was recorded. The plate was then removed and another one was inserted.

After the first lot of plates had been broken, another lot was ordered and were broken in the same way. This second lot of plates consisted of three cast iron plates of the same thickness ($\frac{3}{8}$") as the first lot and with webs one quarter of an inch high and with widths of webs $\frac{1}{4}$", $\frac{1}{2}$", $\frac{3}{4}$" respectively. One tension and two torsion specimens were cast with this lot of plates. Of course, each plate gave one specimen to be tested for bending. These plates and specimens were broken the same as the first lot.

to be altered so that its short arm would be about three or four inches instead of one inch. This would prevent the deflectometer from swinging to such a great angle and allow deflectometer readings to be taken. It was found that the plate would bulge up about .2" for a pressure of about 275 pounds.

Results.

The first lot of plates and specimens was composed of:- Plate No. 1, Plate No. 2, Plate No. 4, Plate No. 5, Bending specimens, No. 1, No 2, No. 4 and No. 5, Tension specimens No. 1 and No. 2, and Torsion specimens No. 1 and No. 2.

The second lot of plates and specimens was composed of:- Plate No 6, Plate No 7, Plate No 8, Bending specimens No 6, No 7 and No. 8, Tension specimens No 3, and Torsion specimens No 3 and No. 4.

From the specimens tested for torsion, the coefficient of elasticity and the ultimate shearing strength of the material can be found. It will not be necessary to enter into a discussion upon the values of the constants of the formula. They have been worked out for the machine with which the torsion tests were made.

For Specimen No. 1:–

The ultimate shearing strength equals:–

$$S_s = \frac{16 M}{\pi d^3} = \frac{16 \times 1492.5 \times 2.66}{\pi \times .7778^3} = 42{,}970$$

d = average diameter of specimen = .7778"

The coefficient of elasticity equals:–

$$E = \frac{32 M l}{\pi \theta d^4} = \frac{32 \times 1492.5 \times 1.94 \times .9375 \times 57.3}{\pi \times .7778^4 \times 3.4} = 1{,}273{,}000$$

For Specimen No 2:–

$$S_s = \frac{16 \times 1492.5 \times 2.50}{\pi \times .7844^3} = 39{,}370$$

$$E = \frac{32 \times 1492.5 \times 1.83 \times .9375 \times 57.3}{\pi \times .7844^4 \times 2.4} = 1{,}645{,}000$$

For Specimen No. 3:–

$$S_s = \frac{16 \times 1492.5 \times 2.34}{\pi \times .7722^3} = 38{,}630$$

$$E = \frac{32 \times 1492.5 \times 1.34 \times .9375 \times 57.3}{\pi \times .7722^4 \times 1.6} = 1{,}923{,}000$$

For Specimen No. 4:–

$$S_s = \frac{16 \times 1492.5 \times 2.14}{\pi \times .7651^3} = 36{,}320$$

$$E = \frac{32 \times 1492.5 \times 1.34 \times .9375 \times 57.3}{\pi \times .7651^4 \times 1.6} = 1{,}996{,}000$$

The mean of these values is:-

Lot 1:-

$$\begin{array}{r} 42970 \\ 39370 \\ \hline 2\,)\,82340 \\ 41170 = S_S \end{array} \qquad \begin{array}{r} 1,273000 \\ 1645000 \\ \hline 2\,)\,2918000 \\ 1,459,000 = E \end{array}$$

Lot 2:-

$$\begin{array}{r} 38630 \\ 36320 \\ \hline 2\,)\,74950 \\ 37475 = S_S \end{array} \qquad \begin{array}{r} 1923000 \\ 1996000 \\ \hline 2\,)\,3919000 \\ 1,959,500 = E \end{array}$$

From the tension specimens, the ultimate tensile strength is calculated:-

Specimen No 1:-

Dimensions of the piece at the break:-

1.039" X .405

It broke at 10 010#

$$S_T = \frac{10010}{1.039 \times .405} = 23,788$$

Specimen No 2:-

Dimensions at break = 1.023" X .398"

Broke at 8860# $S_T = \dfrac{8860}{1.023 \times .398} = 21,760$

This specimen broke in the jaws and cannot be used.

Specimen No. 3:-

Dimensions at break = 1.064 X .423

Broke at 8130#

$$S_T = \frac{8130}{1.064 \times .423} = 18,064$$

The specimens broken in bending give:-

Specimen No. 1:-

Length of beam = 8"

Width of fracture = .906" It broke at 480#

Depth of fracture = .392"

$$S_r = \frac{W l 6}{4 b d^2} = \frac{480 \times 8 \times 6}{4 \times .906 \times .392^2} = 41,372$$

Specimen No 2:-

$$S_r = 48,402$$

Specimen No 4

$$S_r = 46,433$$

Specimen No 5

$$S_r = 49,890$$

The average value for the modulus of rupture

for the specimens in Lot 1 is:-

$$\begin{array}{r} 41\,372 \\ 48\,402 \\ 46\,433 \\ 49\,890 \\ \hline 4\,)\,186\,097 \\ \hline 46{,}524 = S_r \end{array}$$

For Lot 2

Specimen No 6 $\quad S_r = 46{,}138$

Specimen No. 7 $\quad S_r = 46{,}824$

Specimen No 8 $\quad S_r = 49{,}284$

$$\begin{array}{r} 3\,)\,142\,246 \\ \hline 47{,}415 = S_r \end{array}$$

Average of Lots 1 and 2:- 46,969

~~In~~ working up the values to go into the formula, S_r the modulus of rupture is used. This is done because the plates break by bending and not ~~by~~ direct tension. The two lots of plates are also assumed to have the same modulus of rupture in order to compare them. It is very safe to assume this because the modulus of rupture of each lot of plates is

No. of Plate	1	2	4	5	6	7	8
Thickness of Plate = h	.38	.40	.365	.425	.40	.425	.37
Length of side = a	7.51	7.51	7.51	7.51	7.51	7.51	7.51
Width of web = b	.52	.51	.54	.52	.27	.76	—
Depth of web = d	.38	.22	.14	.495	.31	.25	—
Breaking Pressure, Gauge	825	765	550	960	775	850	625
Breaking Pressure, Corrected	605	553	458	739	563	630	402
Ultimate Tensile Strength	23,788	23,788	23,788	23,788	18,064	18,064	18,064
Modulus of Rupture	46,524	46,524	46,524	46,524	47,415	47,415	47,415
Ultimate Shearing Strength	41,170	41,170	41,170	41,170	37,475	37,475	37,475
Coefficient of Elasticity	1,459,000	1,459,000	1,459,000	1,459,000	1,959,500	1,959,500	1,959,500

practically the same and is close enough for cast iron. The thicknesses of the plates must be assumed as constant in comparing the plates. The thickness of the plates varies so little that this assumption can be made.

From the line in Figure 3, it is seen that the points for plates 1, 2, 4, 8 come almost in a straight line. The line should of course go through the point for plate 8 where there are no webs. The point for plate 5 does not come in the straight line. Plate 5 however did not break in the middle as the other plates had broken but broke at the ends of the web along the side of the plate.

The point for plate 5 in not coming on the line shows that the law of the breaking pressure has changed. To get the value of the constant K in the formula, we know that $p_3 = K \frac{d}{h} \frac{s}{a^2}$

or $\quad K = \dfrac{p_3 h a^2}{d S}$

now if we use the point on the curve corrosponding to a pressure of 650 pounds, the height of the web (d) at that point is equal to the thickness of the plate plus the height of the web minus the thickness of the plate. The thickness of plate used, is the average thickness for plates No. 1, 2, 4 and 8. It equals:— .381"

The value of d is therefore

$$d = .839 - .381 = .458$$

The value of p_3 is equal to 650 minus the pressure required to break the plate if it had no web. This pressure from the curve of Fig. 3 is equal to 397 pounds.

Therefore $p_3 = 650 - 397 = 253$

S, a and h are known so that

$$K = \frac{p_3 h a^2}{d\, S} = \frac{253 \times .381 \times 7.51^2}{.458 \times 46969} = .2527$$

The other curve in Fig 3 is one between widths of web (b) and breaking pressures. This curve should go through 397 pounds (the breaking pressure of plates without webs) when the width of the web is zero. The heights of the web should be constant for these plates. The heights of the webs on plates No 2 and No 7 were very nearly constant but the height of the web on plate No 6 was rather large. This plate also was rather badly cast. A heavy fillet of metal was on the plate where the web joined it. This of course had quite a large effect upon the breaking strength as related to the web because the web on this plate was only $\frac{1}{4}$" wide and a little over $\frac{1}{4}$" high. The effect of the excess of height of the web over what it ought to be, of course increased the breaking pressure. This fault can be corrected by finding the breaking pressure which it would stand if it was

the right height. The right height should be .25." The plate in reality had a web .31" high. A pressure equal to

$$K\frac{d\,S}{h\,a^2} = \frac{.2527 \times .06 \times 46{,}969}{.4 \times 7.51^2} = 31.6 \text{ pounds}$$

which must be subtracted from the actual breaking pressure which equals 563 giving the corrected breaking pressure of 531 pounds.

If this value is used for the point in Fig. 3, a new point ⊙ is found. This point however is still too far to the right due to the bad casting of the plate and will not be used. The line however is a straight one and goes through the points for plates No. 2 and No. 7

Now, the value of F is found in the same order as the value of K.

$$p_4 = F\,\frac{b-m}{h}\,\frac{S}{a^2}$$

$$F = \frac{p_4\,h\,a^2}{(b-m)\,S}$$

Let the point corresponding to a breaking pressure of 650 pounds be used.

$p_4 = 650 - 397 = 253$

The value of m is found by taking the mean width of web for plates No 1, No 2 and No. 4. It equals .523"

The value of b for the pressure 650 pounds is .826 Therefore $b - m = .826 - .523 = .303$ and

$$F = \frac{253 \times .381 \times \overline{7.51}^2}{.303 \times 46969} = .382$$

The formula now becomes

$$P = \frac{S}{a^2}\left(2.266\, h^2 + .2527\,\frac{d}{h} + .382\,\frac{b - .523}{h}\right)$$

This formula cannot be used in designing flat plates with ribs on account of the assumptions which have been made, namely $p_3 \propto \frac{d}{h}$ and $p_4 \propto \frac{b}{h}$.

If these assumptions are proven by breaking webbed plates of different thicknesses, then the formula should hold

for all plates, either webbed or not.

It may be that the pressures p_3 and p_4 are independent of the thickness of the plate and only depend upon the web dimensions or $p_3 = K_1 d \frac{S}{a^2}$ and $p_4 = F_1 (b-m) \frac{S}{a^2}$

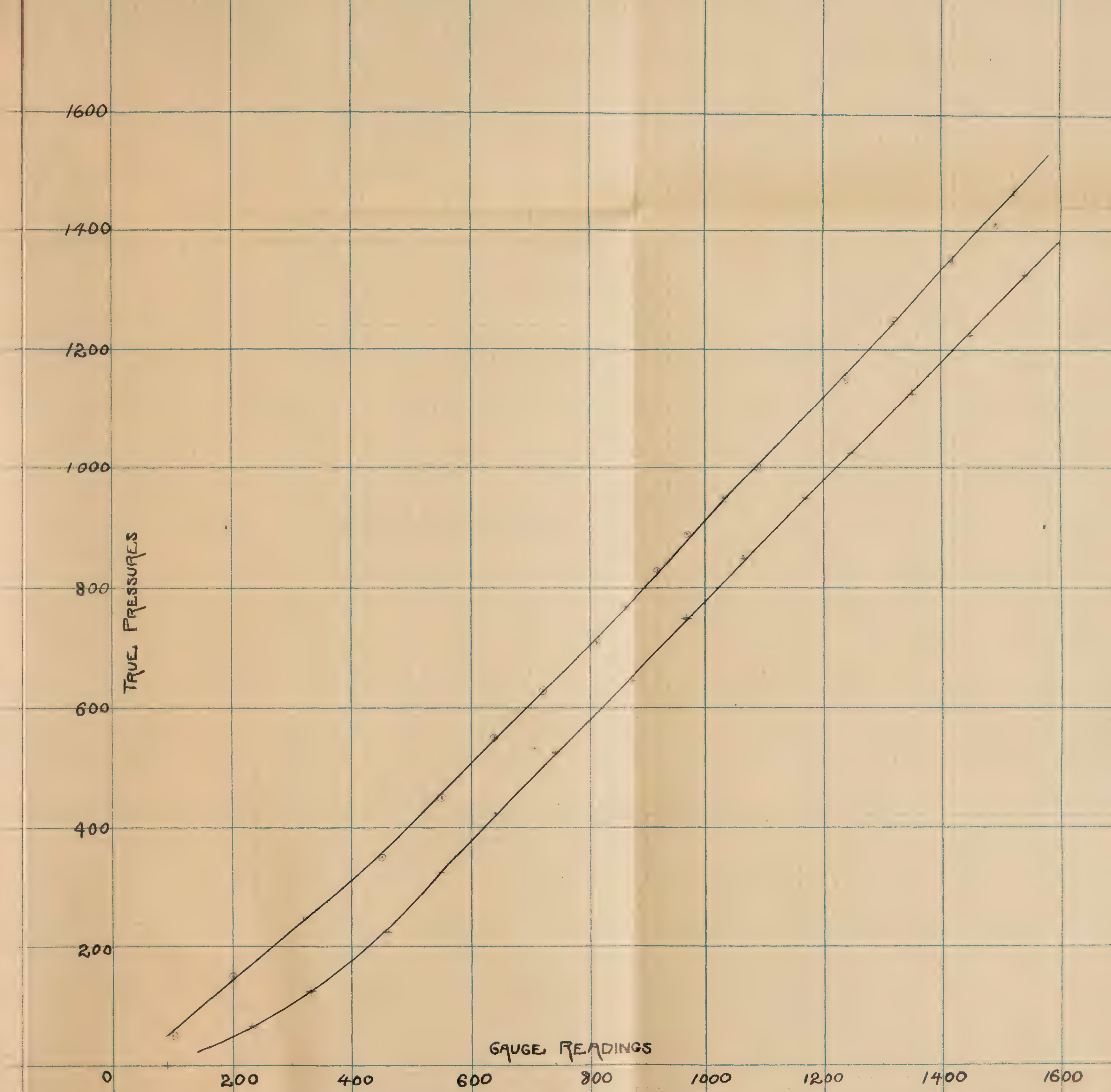
from which the values of F_1 and K_1 could be calculated as before.

The proportions of the web and thickness of plate in order to have the plate of the same strength at the centre as at the sides has been found.

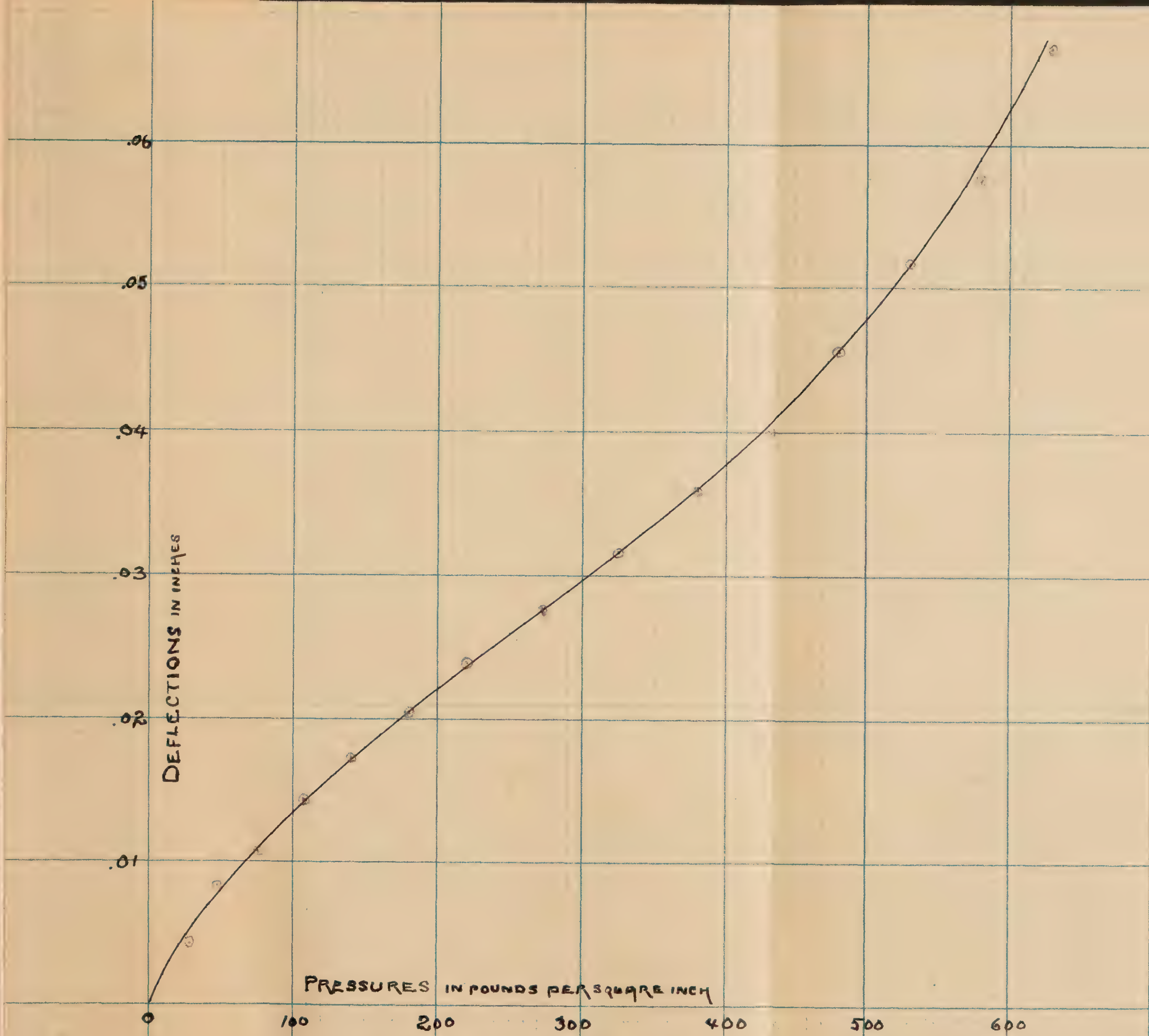
Plate No. 1 broke at the middle while plate No 5 broke at the side. This shows that the right dimensions of the web lie between those of these plates. From Figures 3 it can be seen that plate no. 5 does not follow the same law as the other plates. If a plate with still thicker webs had been broken, a line drawn

for these two points would intersect the line for plates no. 1, 2, 4 at a point where the correct height of plate web would be known. As it is now, the web dimensions for plate no. 1 will be assumed to be the correct ones. The dimensions for a ribbed plate taken from plate no. 1 would be:—

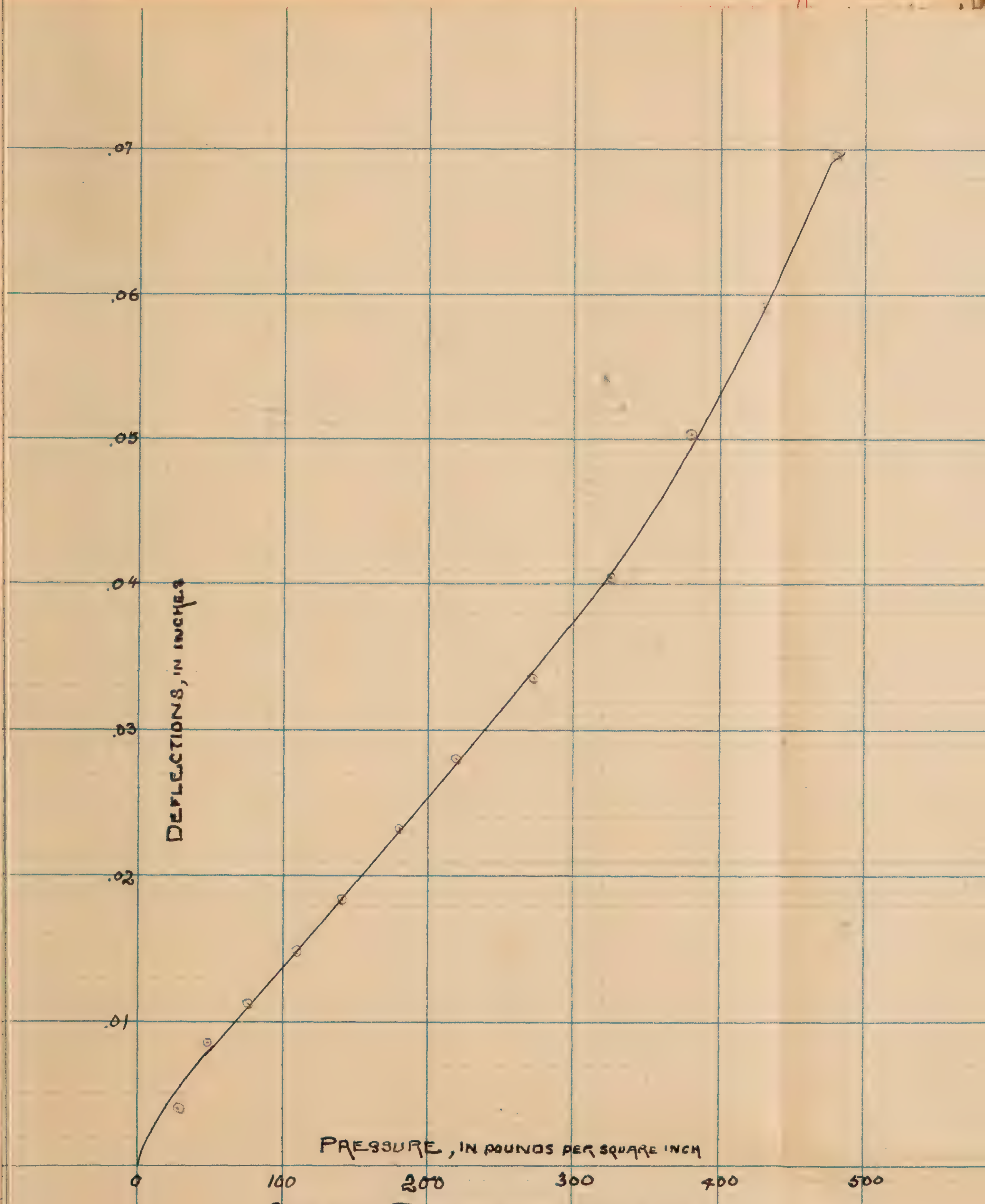
$$d = h \qquad b = \frac{52}{38} h = 1.37 h$$



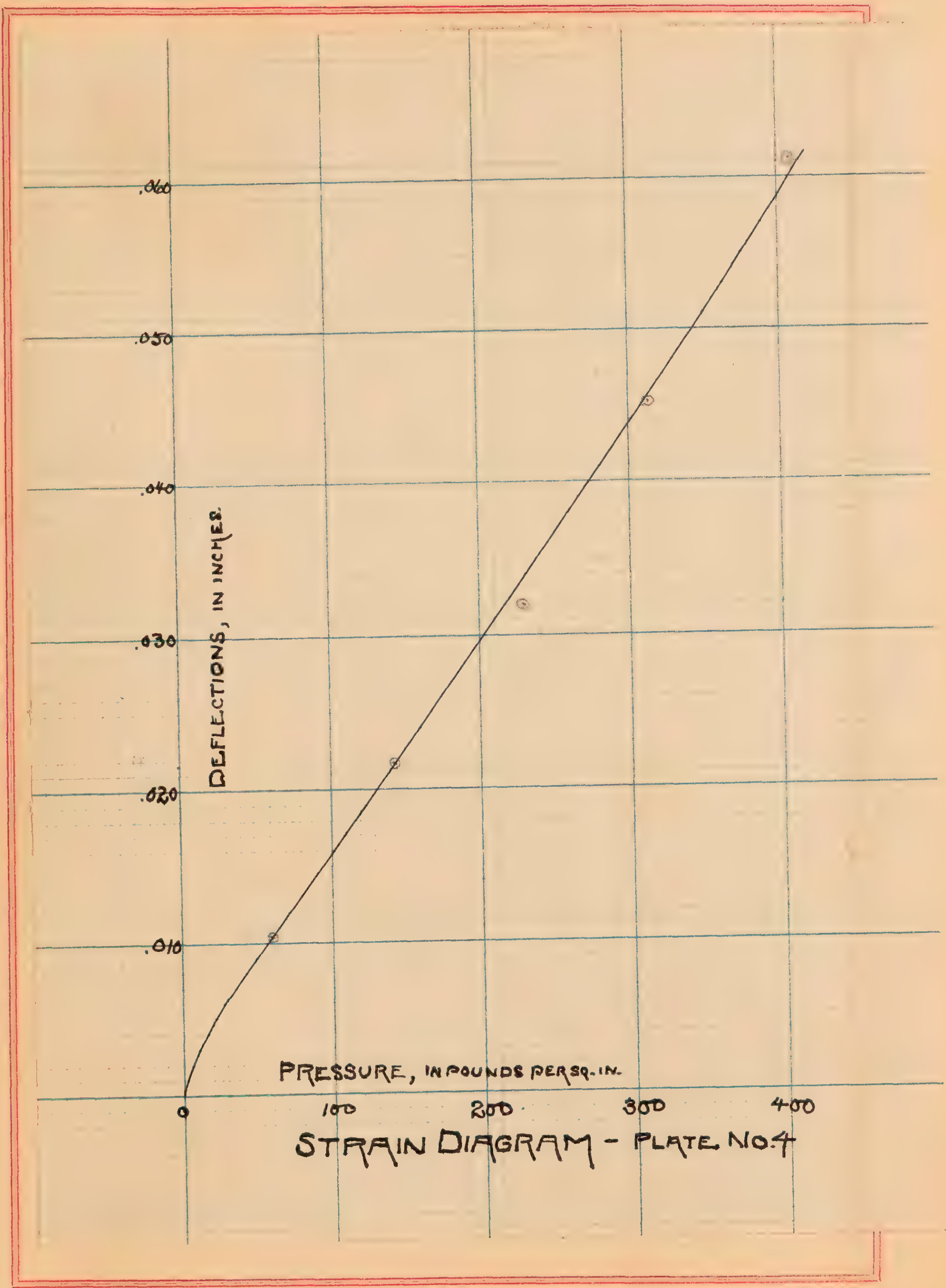
Calibration Curve of Hydraulic Pressure Gauge, No. 28046



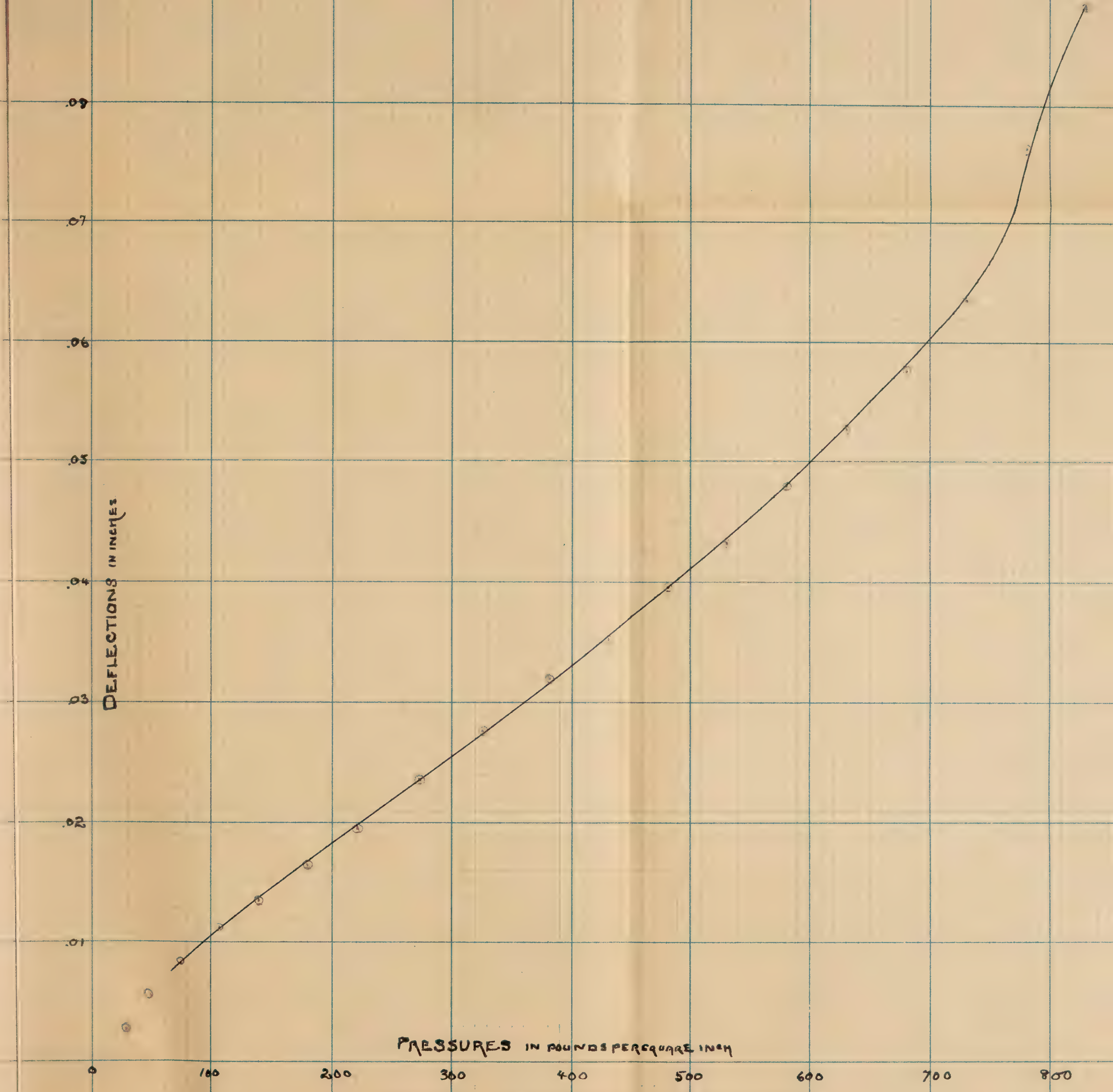
STRAIN DIAGRAM - PLATE No. 1



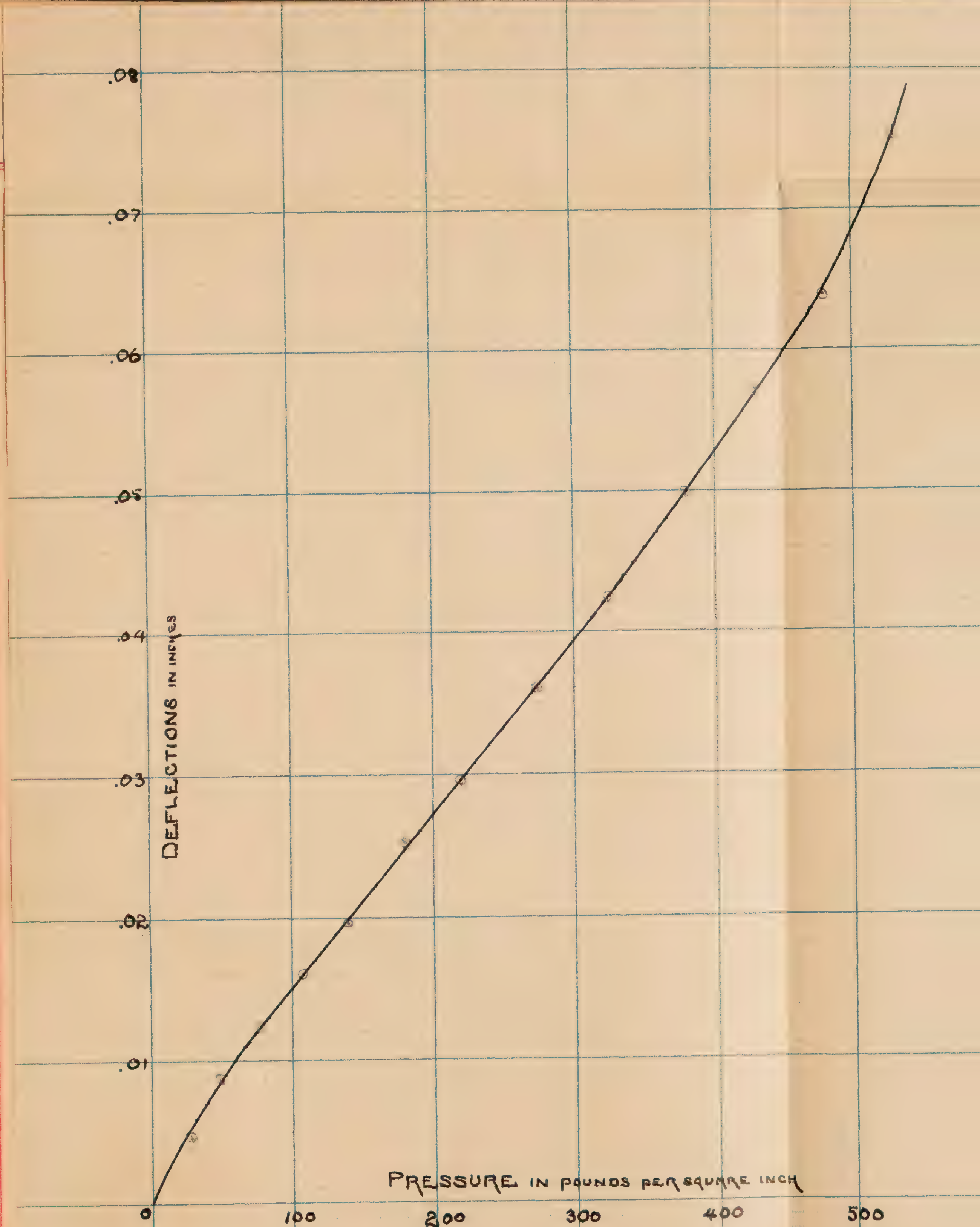
STRAIN DIAGRAM - PLATE No. 2



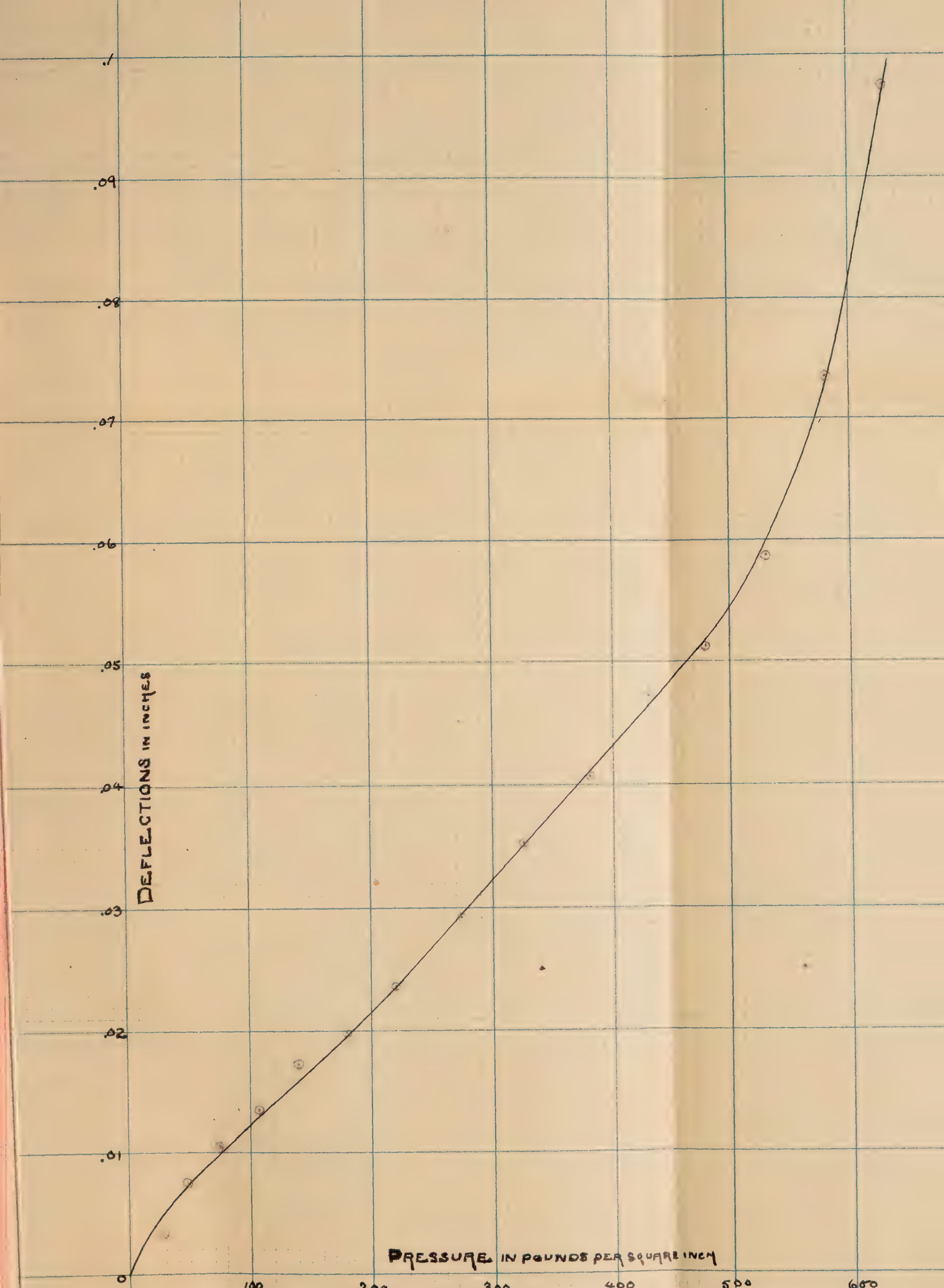
.060
.050
.040
.030
.020
.010
DEFLECTIONS, IN INCHES.
PRESSURE, IN POUNDS PER SQ. IN.
0
100
200
300
400
STRAIN DIAGRAM - PLATE NO. 4



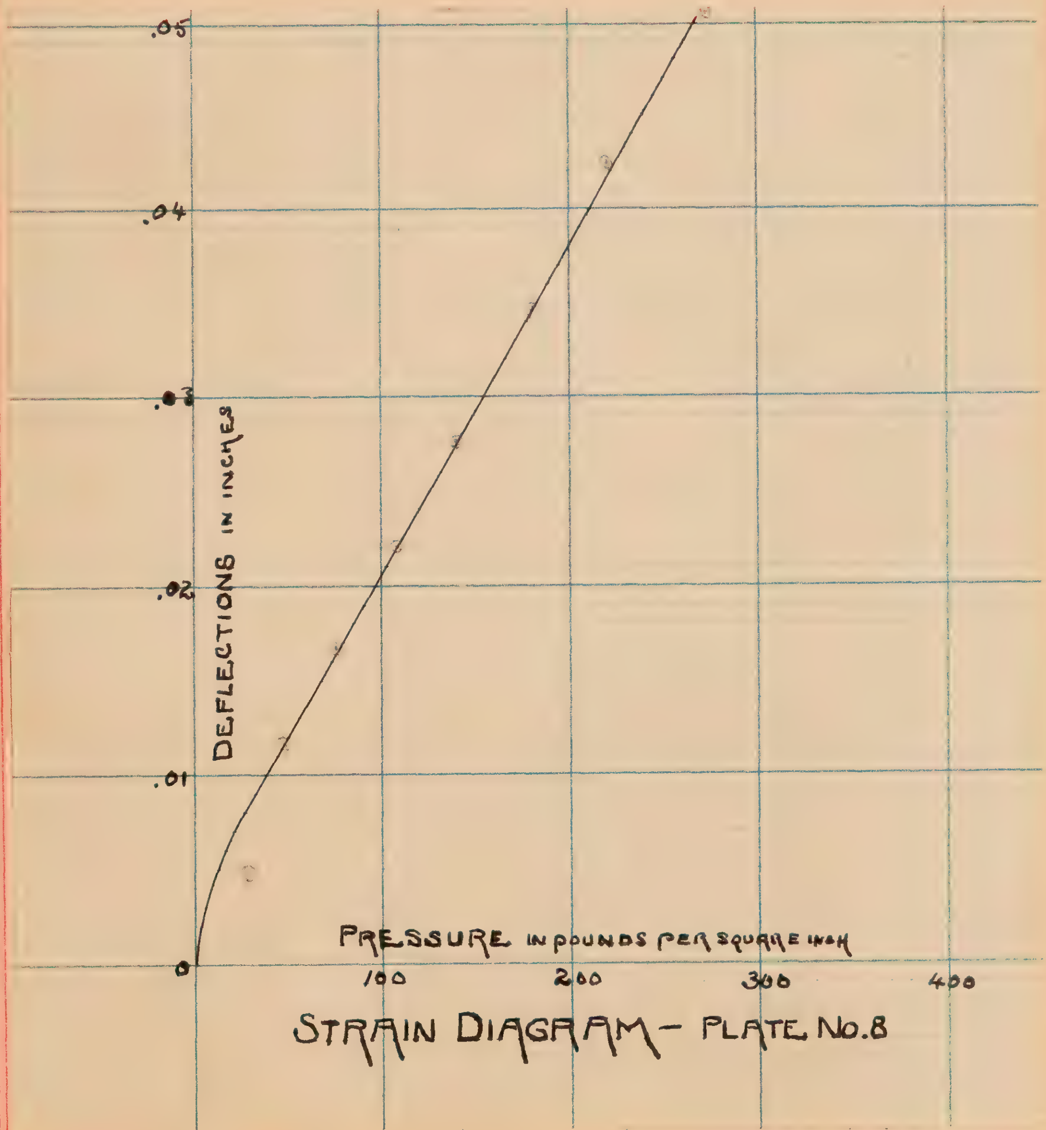
STRAIN DIAGRAM — PLATE No. 5



STRAIN DIAGRAM – PLATE No. 6



STRAIN DIAGRAM - PLATE No. 7



STRAIN DIAGRAM — PLATE No. 8